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Modeling Ephemeral Settlements Using VHSR Image Data and 3D Visualization – the Example of Goz Amer Refugee Camp in Chad

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Keywords: Remote Sensing, modeling ephemeral settlements, VHSR Image, 3D Visualization, refugee camp in Chad

Abstract: Crisis situations in the aftermath of man-made or natural disasters lead to increasing volumes of internally displaced people and refugees. The recent crisis in Darfur for example has mobilized more than 800,000 people, about one fourth of them being accommodated in refugee camps in Eastern Chad. More permanent camps, like Goz Amer, have converted to ephemeral settlements over time, but even there aid agencies report on limited knowledge concerning the actual number of inhabitants and changes due to reallocations. This paper demonstrates that full usability of very high spatial resolution (VHSR) data for rapid information delivery relies on well-established workflows for the transformation of raw image data into ready-to-use information. On prototype level this workflow couples automated analysis of high-resolution image data with GIS-based visualization techniques. Extracted dwellings and habitation structures are used as proxies for an estimation of camp inhabitants. The provision of a geo-referenced, pseudo-realistic 3D-scenario is considered an effective means for coordinated humanitarian aid delivery. For the study on Goz Amer camp, a 3.1 km^2 subset of a QuickBird scene has been pan-sharpened and resampled to a 0.6 m ground resolution. Sobel-filtering created an edge-enhanced product, which was segmented in a fine scale representing relevant dwelling structures at best. By means of rule-based classification and fuzzy operators the segments were assigned to different dwelling types (including orientation of main axis), fences/walls, bare soil/sand, single trees, and vegetation. Accuracy assessment was done using a visually interpreted reference layer, focusing on tents. The number of extracted tents (2,263) was multiplied by an estimated factor of average family size, considering a specified level of uncertainty. An overall number of 20,362 camp inmates was calculated. This number can be spatially disag-

Zusammenfassung: *Modellierung temporärer Siedlungen mittels höchstauflösender Fernerkundungsdaten und 3D Visualisierung – am Beispiel des Flüchtlingslagers Goz Amer im Tschad.* Ausgelöst durch Krisensituationen nimmt weltweit die Zahl der Binnenflüchtlinge und Grenzflüchtlinge zu. Die aktuelle Krise in Darfur beispielsweise hat mehr als 800,000 Menschen mobilisiert, wovon ungefähr ein Viertel in Flüchtlingslagern im östlichen Tschad untergebracht ist. Permanentere Lager wie Goz Amer können aufgrund der stabileren Struktur als vorübergehende Siedlungen aufgefasst werden. Selbst dort herrscht aber bei den Hilfskräften und -organisationen nur begrenztes Wissen hinsichtlich der tatsächlichen Zahl der Bewohner und der Dynamik durch Umverteilungen zwischen den Lagern. Diese Studie zeigt auf, wie räumlich höchstaufgelöste (VHSR) Daten für eine rasche Bereitstellung relevanter Informationsanlieferung mittels eines Workflows eingesetzt werden können. Auf Prototypniveau verknüpft dieser die automatisierte Analyse höchstauflösender Bilddaten mit GIS-gestützten Visualisierungstechniken. Extrahierte Zelte werden zusammen mit anderen Wohnstrukturen (Hütten, Zäune) als Indikatoren für eine Schätzung der Lagereinwohner verwendet. Die Erstellung und Vermittlung eines georeferenzierten, pseudo-realistischen 3D-Scenarios wird als ein wirkungsvolles Mittel für koordinierte humanitäre Hilfsaktionen betrachtet. Für die Studie wurde ein 3,1 km^2 großes Subset einer QuickBird Satellitenbildszene pan-geschärft und auf 0,6 m resampelt. Durch Sobel-Filterung wurde anschließend ein kantengeschärftes Produkt erzeugt, das in einer feinen Skala segmentiert wurde, um relevante Strukturen optimal wiederzugeben. Mittels regelbasierter Klassifikation und Fuzzy-Operatoren wurden die Bildsegmente unterschiedlichen Behausungstypen zugeordnet, d. h. Zelte (einschließlich Lagebestimmung der Hauptmittelli-

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gregated by applying a regular (here: 50 m * 50 m) grid or using administrative camp units. Finally, utilizing a library of 3D-symbols and ancillary digital elevation data, a 3D scene was generated providing a pseudo-realistic impression of the overall situation and setting of the camp.

nie), Hütten und Zäune. Darüber hinaus wurden grobe Landbedeckungsklassen im Camp ausgewiesen, also offener Boden bzw. Sand, größere Einzelbäume und Vegetation. Die Genauigkeitsabschätzung erfolgte über einen Vergleich mit einer visuell interpretierten Datengrundlage. Dabei wurde das Augenmerk vor allem auf die extrahierten Zelte gelegt. Die 2263 extrahierten Zelte wurden mit einem aus Literaturangaben geschätzten Faktor multipliziert, wodurch auf die Gesamtzahl der Lagerbewohner geschlossen werden konnte. Diese beläuft sich auf 20362 Bewohner. Die Gesamtzahl kann räumlich mithilfe eines regelmäßigen Raster oder administrativen Lagereinheiten disaggregiert werden. Schließlich wurde eine Bibliothek mit 3D-Symbolen erzeugt und mithilfe eines digitalen Geländemodells (DGM) eine 3D Szene erstellt, die einen pseudo-realistischen Eindruck der gesamten Situation vermittelt.

Introduction

In many places of the world, but with an emphasis in Central and Eastern Africa, man-made disasters such as civil wars or other aggressions against the civil population have mobilized large numbers of affected people. The ongoing crisis in the Darfur region (Western Sudan) has caused more than 800,000 people to leave their homes and villages (Caritas 2004) and is considered one of the most disastrous humanitarian catastrophes recorded recently.

The Darfur crisis

Sudan, a federal state consisting of 26 states since 1994, is the largest country in Africa covering an area of 2.5 million km^2 and stretching between 4° to 22° N and 22° to 38° E, respectively. The Nile river system is the predominant surface water system; 64 % of the Nile river basin is located in Sudan, which makes up four fifths of the countries total area. Effects of climate change on sub-Saharan ecosystems have caused an extension of arid zones and have developed a further potential for the destabilization of the traditional economic structure. Sudan's population is 34.3 million (2004) with an annual growth rate of 2.2 % (FAO). The population distribution shows a great imbalance in accordance with climate conditions. Exceptions to this trend are the areas of confluence of White Nile and Blue Nile (Khartoum) and the area of confluence of Main Nile and Atbara River. Economically, factors of spatial disparities contribute to the imbalance between Khartoum and the South: the distribution of resources and political power, industrial infrastructure, and transport facilities. In Darfur, population concentration is above the average, especially south of 15°N. The Darfuri can be divided into the local, non-Arab indigenous inhabitants of the region and the peoples of Arab descent. Internal southward shifts to this area have put pressure on sedentary farmers of the more humid areas. The Darfur crises can be regarded as a manifestation of the Sudan crises on Darfurian territory. Possible driving forces are generally the same ones as in the North-South conflict whereas the existence of oil deposits in the war-stroke areas of Darfur is presently not proved. The geographical situation of Darfur is a landlocked position with poor road-infrastructure and large distances to navigable rivers. This position acts as barrier for Sudan as a resource provider. The transfer from resource-based to ethnic-based argumentation is founded in the hardening of the ethnic divide, which begins to act once a conflict has started.

In addition, the southern Sudanese regions claim equality of political power on the national level. They request an economic development on equal terms of the Sudan country. Some of these North-South-type conflicts do not take place in southern Sudan nevertheless they can be regarded as proxy wars, such as in the case of the Darfur conflict which has been ongoing for the last decades with changing intensity and geographic extent. More than three million people live in camps as internally displaced persons (IDPs), or had crossed the Chadian border for staying there as refugees (Reeves 2005). It has become complex due to the centralization of power in Khartoum and the involvement of south Sudanese rebels in the 1990ies entering the Darfurian region. In spite of the high revenues of Sudan's oil-industry, agriculture remains the most important and likewise, the most vulnerable branch of the country's economy. The deterioration of the existing agricultural potential has an impact on food supply and poverty in general. The land reform in 1994 had probably the strongest impact on the relationship between the periphery and the Khartoum based central government.

VHSR imagery and a workflow for information delivery to aid support

The co-ordination of targeted relief support from international organisations like the United Nations High Commissariat for Refugees (UNHCR), the World Food Programme (WFP) or FAO requires, as one of the most crucial prerequisites, exact and spatially disaggregated numbers of affected people (Ehrlich et al. 2004). This includes up-to-date knowledge about the population living in refugee camps. But even if the number of camp inmates was recorded initially, internal reorganisations and inter-camp re-allocations of refugees may change the overall picture in the short-term. Means are needed for rapid information update, preferably utilizing automated and repeatable procedures different from manual counting or listings (FAO, oral communication). In principle, satellite remote sensing data and adequate analysis techniques fulfil these criteria, though with constraints. Harvey (2002) points out three important aspects why population estimation based on satellite imagery is still a challenging task. First no direct link exists between population and reflectance characteristics as in land cover mapping. Secondly, a qualitative variable like land cover is more readily classifiable across the entire image than a quantitative one. Thirdly ground truth information for population estimation is usually available on aggregated levels only. Four approaches for population estimation from remote sensing data are given by Lo, 1986, (cited in Harvey 2002): the first, counting of dwellings, has been a domain of visual image interpretation for a long time. The second, measurement of urbanised areas, uses allometric mapping and relates population to the size of city footprints. It also includes other indicative methods such as nightlight mapping. The third, measurement of areas of land use types, uses statistical links between population figures and land-use (dasymetric mapping). The fourth, automated digital image analysis returns to a more direct population mapping by automating dwellings counts. Today the availability of very high spatial resolution (VHSR) data along with automated analysis techniques may move the latter a significant step forward. For a general overview on current and potential use of satellite imagery with regard to UN humanitarian organizations and their operations see Bjorgo 2002. Even with full operational processing and analysis of high-resolution image data the question arises: may satellite remote sensing really contribute to gain a better picture on how population structure of a refugee camp is composed and which dynamics occur there?

Within the EU-Network of Excellence GMOSS (Global Monitoring for Security and Stability) a workflow for high-standard information transformation and delivery

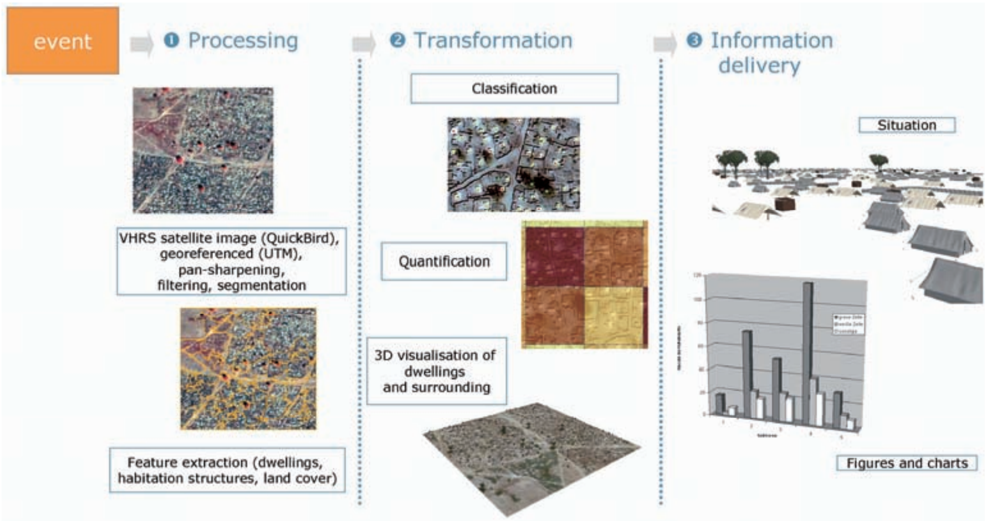

Fig. 1: Triggered by a certain event or crisis situation very high spatial resolution satellite data is acquired. These are pre-processed, geo-referenced and integrated using a global reference tool. Extraction of dwellings and other population-relevant features is performed using object-based image analysis. Based on photographs and descriptions from the specific setting, a library of different dwelling types is composed. Such 3D features are then placed on the locations derived by automated image classification.

has been established. The workflow builds upon a sequence of automated image analysis and visualisation techniques for modelling population-relevant features. It aims at transforming imaged scenes to ready-to-use and policy-relevant information. As illustrated in Fig. 1, the workflow includes the entire chain of pre-processing, feature extraction, classification, quantification and pseudo-realistic 3D visualisation. The latter provides a pseudo-realistic representation of the situation, complemented by existing or derived ancillary data sets like a digital elevation model (DEM) or a coarse-scaled land cover set. Delivering a complete picture of the very situation and the respective crisis area, including figures and charts, it may directly support relief actions or other fine-scale operations.

Case study Goz Amer

The Goz Amer camp

During recent aggressions in the Darfur region, about 150,000 refugees crossed the border to Chad (Welthungerhilfe 2004). To date, about two third of those people live in one of the refugee camps established and maintained in the Eastern Chad (Caritas 2004). The camp Goz Amer (see Fig. 2) is situated about 100 km west of the Chadian/Sudanese border. The total amount of refugees registered at the UNHCR was 18,341 (UNHCR Camp statistic of August 2004).

An apparently regular and stable pattern of tents and other pertaining structures (like fences or huts) justifies the term ‘ephemeral settlements’ as a metaphor for the semi-permanent character of the camps. Although only a minority of the camps are planned and designed from the government, the term ‘informal settlements’ may be misleading in this context; rather emphasizes the lack of juridical justification of dwelling structures.

Data sources and pre-processing

From an 11bit QuickBird scene, recorded in December 2004 and comprising an area of 64.4 km^2, a subset was created showing

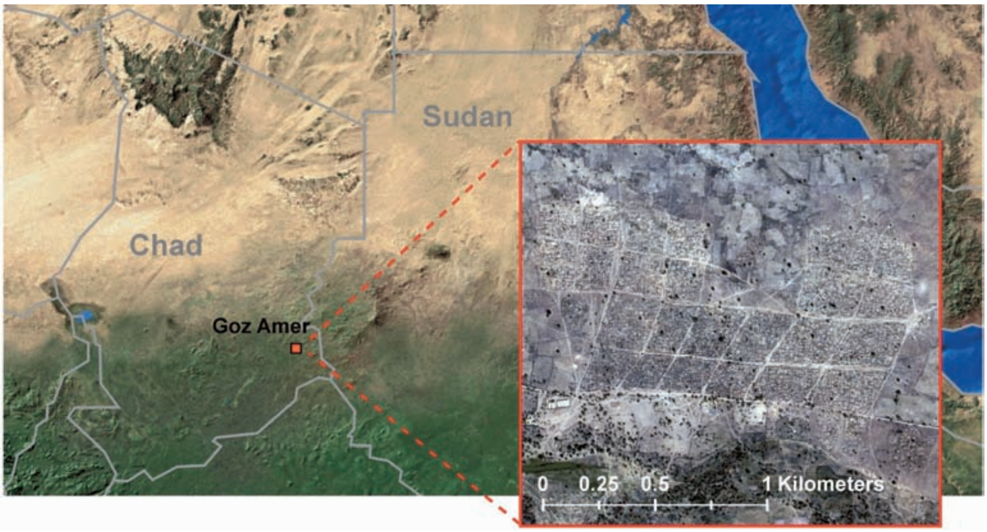

Fig. 2: The Sudanese refugee camp Goz Amer, Eastern Chad.

the Goz Amer camp and the near surroundings with a total area of 3.1 km^2. The scene was pre-registered in UTM-34N (WGS-84). Resolution merge led to a ground spatial distance of 0.6 m. Pan-sharpening was done according to LIU (2000) using an image fusion model implemented in the software package Erdas Imagine 8.7. The method maintains original spectral values to a large extent (> 90 %) and enables deriving detailed information of small structured and high homogeneous areas. A 3*3 Sobel filter matrix was used for edge detection and enhancement. This was done on the resolution-merged blue channel as proposed by LANG & TIEDE (2005). The additional information content of the Sobel filtered image layer was required for delineating linear objects during segmentation. Image segmentation itself was done using a region-based, local mutual best fitting approach (BAATZ & SCHAEPE 2000) as implemented in the software eCognition 4. We applied two scale levels for targeting different size-constraint categories of dwelling structures (see Tab. 1).

Tab. 1: Segmentation settings (L = Level, SP = scale parameter, SW = shape weighting, CPW = compactness weighting).

L	SP	SW	CPW	Remarks
2	25	0.2	0.8	bright medium-sized shelters and big shelters well segmented
1	15	0.2	0.5	dark small shelters well segmented

Class definition and classification

Classes of concern within the camp area are known: the primary idea was to determine tents, huts and other habitation structures. Owing to this, in a knowledge-driven approach, an appropriate model was established, which supports extracting the expected object types. We used a rule-based production system with specific descriptive features and fuzzy rules (see Tab. 2). We differentiated between inheritance hierarchy and semantic hierarchy, the first addressing the inheritance of class descriptions from parent to child classes; the second referring to the logical coherence among different classes.

Objects of interest were extracted as single objects. Therefore the number of image ob-

Tab. 2: Class definition containing inheritance and semantic grouping, features and rules, class area and percentage of total area.

Class name	*Inheritance (◘ parent/▣ child); semantic grouping (**O** parent/⊙ child); single class (◇)*	*Features/rules (⌘= membership to, ◆ = mean value of, D = density, B = brightness, C = compactness, % = relative border length to)*	*Class area (ha)/% of total (3.1 km²)*
Bare soil total	**O** of *bare soil* and *bare soil shadow*		
Bare soil	⊙ of *bare soil total*	⌘ all other classes < 0.2	131.1/43.4
Bare soil shadow	⊙ *bare soil total* ▣ of *shadow*	% *Single trees shadow* [0.4–0.5]	–
Fences	◇	**B** [350–340]; **D** [0.65–1.3] ⌘ [0.1–1]; ◆ Sobel [30–50]	5.7/1.9
Shadow	◘ of *bare soil shadow* and *tree* (shadow)	**B** [220–390]	–
Single trees total	**O** of *single trees* and *tree* (shadow)	–	–
Single trees	⊙ of *single trees total*	NDVI [0.24–0.29]	11.3/3.7
Tree (shadow)	⊙ of *single tress total* ▣ of *shadow*	% *Single trees* neighb. [0.3–0.8]	––
Tents bright total	**O** of *tents bright and tents bright border*		
Tents bright	⊙ of *tents bright total*	◆ Blue layer [360–370]	1.5/0.5
Tents bright border	⊙ of *tents bright total*	**C** [1.5–1.7]; ⌘ [0.1–1] **%** *Tents bright* neighb.[0.35–0.6]	-
Traditional shelter	◇	Area [3–20 (m²)] ; **B** [300–400] **C** [1–1.5] % *Tents bright* neighbours [0]	1.9 / 0.7
Vegetation outspread	◇	NDVI [1.35–2.55] ∧[0.03–0.04] ratio NIR [0.24–0.25]	126.2 / 41.8

jects directly corresponds with the actual number of dwellings or habitation structures. This especially applies for 2,263 objects of the class *Tents bright* (i. e. UNHCR tents of 12 to 20 m^2) and 2,640 objects of the class *Traditional shelter* (i. e. self made, straw covered huts of 4 to 24 m^2).

Accuracy assessment

Accuracy assessment using ground truth information is usually hampered in crisis situation. We therefore created a reference data set by visual interpretation and manually digitizing relevant dwelling structures. In order to represent a sufficient part of the whole camp a grid of 100 m cell-size was superimposed on the whole scene (Fig. 3). 70 out of 280 cells were randomly selected and used to digitize tents and shelters, represented as mid-points. Altogether, 80 % of these were extracted correctly (point-in-polygon). More specifically for *Tents bright* the following applies: out of 790 manually digitized *Tents bright* mid-points, 235 were not contained by a classified *Tents bright* polygon. This corresponds to a producer accuracy of 70.3 %. By a buffer of 1.2 m (two pixels) the amount of misclassified tents could be corrected by 74 tents. Under this condition,

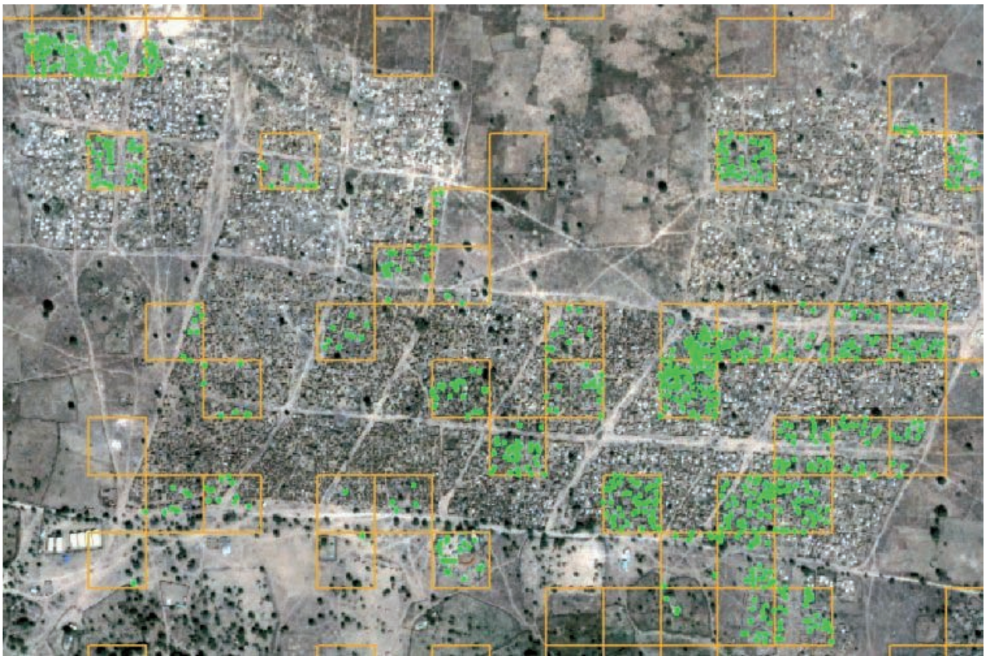

Fig. 3: Accuracy assessment in 70 random cells. Green dots indicate manually digitized tents (790 altogether).

producer accuracy bright tents increases to 79.6 %.

Estimation of camp population

Appropriate and quick population estimation based on extracted objects is feasible. The proposed metric is based on an assessment with the help of eyewitness of an IDP-Camp in Darfur (oral communication with T. Spielbüchler). One assumption, also backed by photographs on web pages, is the use of traditional dark shelters for cooking and staying during daytime only; they are neither used nor suitable for sleeping. Consequently, they give a clue for the estimation process but are not directly related to the number of inmates. A cautious estimation projecting the number of the extracted bright tents by a factor of an average family size provides a realistic, though inexact, number of inmates. A factor of 1.2 (i. e. 20 % according to the producer's accuracy) results in a total number of bright tents of 2,715. Assuming that the average West-Darfurian family has between seven and eight family members[1] this would account to a total number of 20,362.5 camp inmates (i. e. 2,715 times 7.5). This value slightly overestimates the real number of around 18,500 at that time.

Spatial (dis-)aggregation of camp population

Since information about population is spatial explicit (i. e. available on the tent level), the overall amount of camp inmates can be aggregated or disaggregated to any spatial subunits of the camp. This may be administrative subdivisions for management related tasks or a regular grid of e. g. 50 m * 50 m cells for analytical purposes. Fig. 4 shows an example of the latter for analysing population densities in a subset of the camp.

[1] http://www.Sudanreeves.org (accessed: 11/2005)

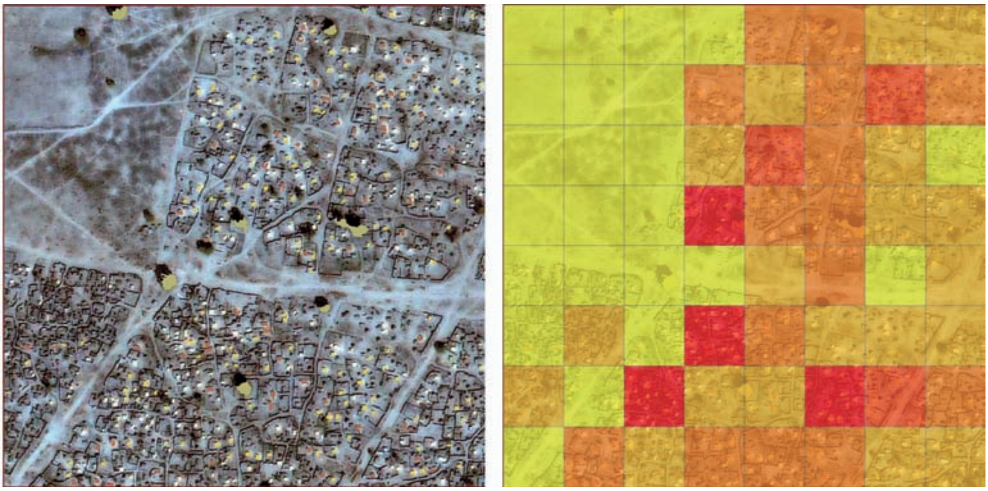

Fig. 4: Extracted dwellings (left) and population densities in a 50 m * 50 m cell grid (right).

Data integration and pseudo-realistic 3D visualization

Visualization of the derived information can be a benefit to the local administration of refugee camps. It also provides rescue teams an overview about the situation they may expect there. Pseudo-realistic 3D visualisation reveals a better impression with more self explaining information, especially to people who are not experienced in reading maps. The workflow discussed above offers the possibility for a gapless chain of information extraction, information delivery and 2D/3D visualization. Fig. 5 gives an overview about the required steps for data integration and visualization. This was conducted using the ArcGIS Extension 3D Analyst supporting data integration and visualization while simultaneously providing GIS analysis functions. Information extracted from the image data comprises: (1) relevant dwelling structures exported as anchor points (i. e. centroids of the extracted objects), which hold attribute information about the dwelling type and main direction (orientation); (2) linear fence structures as centrelines of fence objects; (3) land cover classification (bare soil, vegetated areas, single trees). A 3D symbol library containing three main dwelling types (i. e. large/small tents, traditional shelters) has been constructed in Autodesk 3D Studio Max using image material of the camp. Terrain height information was obtained from SRTM (Shuttle Radar Topography Mission) data.

The resulting scene is a real-time visualisation enabling the users to change between different perspectives, navigate in the third dimension and easily create and export prerendered animations. The use of a 3D symbol library adapted to the current situation gives a much better impression than using wildcard symbols for different dwelling types. Due to the small amount of dwellings types in this example, the effort for creating such a symbol library is limited. Further improvement of the pseudo-realistic impression could be reached by automatically adjusting the symbols. This was done by using the main direction of the extracted dwelling object and attaching this information as an attribute to the anchor point layer. Once created, the 3D scene is not the end of the line: It is a flexible model to change easily data sources, integrate new or updated information and enables the use of GIS analysis functions, e. g. surface analysis, spatial queries, viewshed analysis etc.

The whole scene has been transferred to a globe environment (here: ArcGlobe),

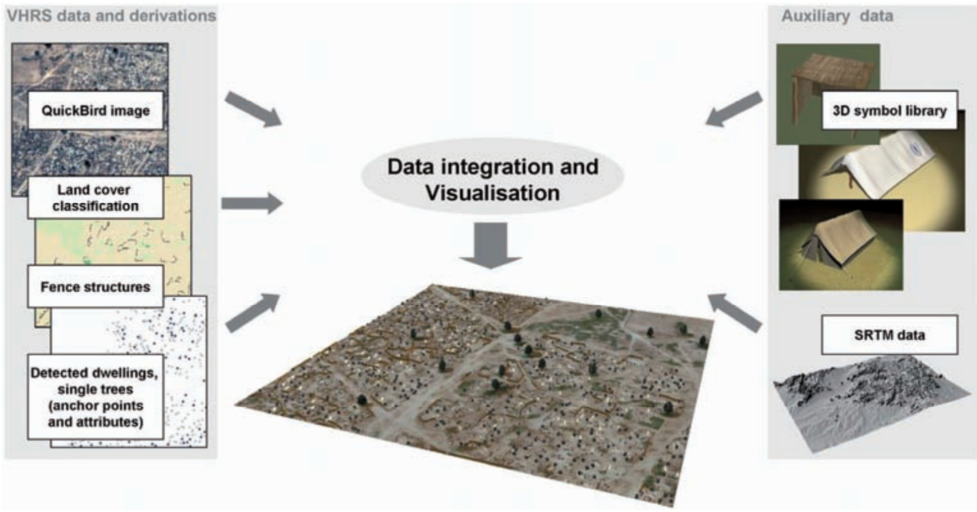

Fig. 5: Overview of data integration for pseudo-realistic 3D visualization.

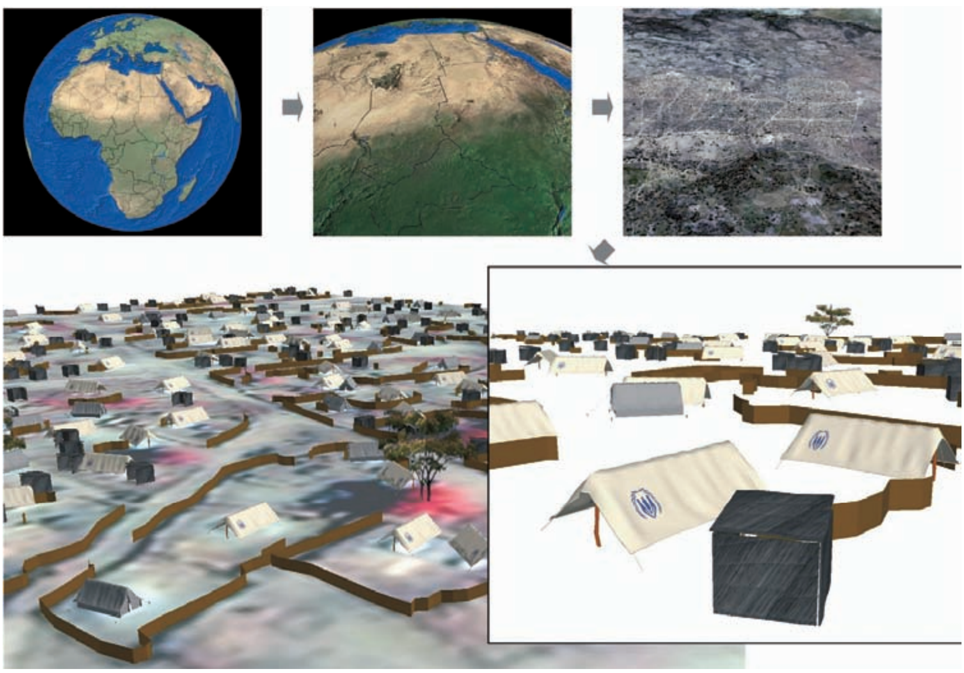

Fig. 6: Pseudo-realistic visualization in a globe environment.

which allows for its integrating the scene into the regional context. Hence, an infinitely variable and scale-independent zoom from global over continental-regionally to locally is supported (cf. Fig. 6). In addition it might be of interest to provide the result within free available 3D data viewers (e. g. ArcReader), overcoming problems of information dissemination due to restrictions in software licensing.

Discussion

Population mapping and monitoring

Population monitoring in a refugee camp under the given conditions differs from population monitoring in more common places. For the present research, the detailed spatial resolution has been a great advantage, but a pixel size qualifying as a satisfying resolution may even be higher. A rough and quick estimation is possible – also considering that field research is impossible in some remote areas, especially within a short period of time. In the Goz Amer study, the pan-sharpened VHSR data material allowed for detecting entire objects of varying size and geometry, without leaving scattered remnants of incoherent pixels. The concept of neighbourhood, distance and location was successfully introduced, especially in shadowed areas. Spatial relationships helped to discern between classes, where high similarity in spectral behaviour occurred. However, spatial concepts alone did not separate fence structures from other elongated dark objects. Evidently fence objects interfered with other edge features accentuated by the Sobel edge detector. Massive fluxes of refugees may occur within one day. Hence, quick information generation regarding the movement or replacement of people needs to be provided to administration and relief support. Change detection techniques and rapid multi-temporal analysis are to be integrated in the workflow. This is one of the major research tasks for the future. Difficulties arise, as a binary comparison of absence and presence of tents being erected or dismantled may not reflect the number of people living there at this particular moment. Whole sections of the camp may be abandoned for a certain period of time. In this case night time data (e. g. from the *Defence Meteorological Satellite Program*, *Operational Linescan System*), could provide valuable additional information by indicating human activities (bonfires, stove cooking). No doubt, the use of VHSR data such as QuickBird or Ikonos is expensive. On the other hand, the *International Charter on Space and Major Disasters* obliges data providers and analysts for a close collaboration in crisis situations without financial barriers. The QuickBird data used for this study has been obtained through this charter. Even if data are not for free, from a humanitarian point of view it makes sense spending the money on high quality data in order to adequately implement supporting actions. Finally, the detailed scale on which the analysis performs and the expected higher quality of the result may lead to a more precise and cost-effective help, which could justify the additional costs for data acquisition.

Visualization and relief support

Discussions on the usefulness of a pseudo-realistic 3D visualization for relief operations arose several times within the GMOSS expert group. It was concluded that this can be seen as a novel and complementary approach for standard mapping. It implies additional value to be considered in crisis management. Mainly the flexibility is appreciated. Admittedly the degree of realism is a crucial point: for example the degree of detail concerning the 3D symbol library may pretend a higher accuracy than the use of standard symbols. Also the orientation of the 3D symbols derived from the main line of the extracted objects generates a more realistic impression compared to equally orientated symbols. But still the question remains: which of these alternative visualizations really correspond to the nature of this particular refugee camp? Is it the strict and ordered placement of tents or an irregular orientation along the main axis as depicted on the imagery? Is then the visualisation maybe too much 'pseudo'?

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